Point-contact investigations of challenging superconductors: two-band MgB_2, antiferromagnetic $HoNi_2B_2C$, heavy fermion UPd_2Al_3, paramagnetic $MgCNi_3$.

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Abstract

An overview on recent efforts in point-contact (PC) spectroscopy of title superconductors is given. Distinct phonon features and crystalline-electric-field effects are observed in PC spectra of $HoNi_2B_2C$. Results of study of superconducting (SC) gap and excess current versus temperature and magnetic field reflecting specific multi-band electronic structure in MgB_2 are presented. The nature of the extremely nonlinear $I(V)$ curves in the antiferromagnetic (AF) and SC state are elucidated for UPd_2Al_3 break-junctions and $MgCNi_3$ point contacts.

Key words:
MgB_2, $HoNi_2B_2C$, UPd_2Al_3, $MgCNi_3$, superconducting gap, electron-phonon interaction, point contacts

By point-contact (PC) investigations both the superconducting (SC) order parameter and PC electron-phonon interaction (EPI) function $\alpha^2_{\rm PC}2F(\omega)$ can be established studying the first and second derivatives of the $I(V)$ characteristic of PC's [1]. Thus the PC spectroscopy could be helpful to illuminate details of EPI and characteristic of SC state in the title compounds.

We have measured PC spectra of $HoNi_2B_2C$ with pronounced phonon maxima at about 16 and 22 mV, a smeared maximum near 34 mV, and shoulder around 50 mV (Fig. 1). All these features correspond well to the neutron phonon DOS of nonmagnetic related compound $LuNi_2B_2C$ [2], only the high energy part of the PC spectrum is remarkably smeared. The maximum around 10 mV might be connected with CEF excitations, observed in this range by neutron scattering [3], while the maximum around 4 mV has definitely connection with magnetic order, since it disappears above

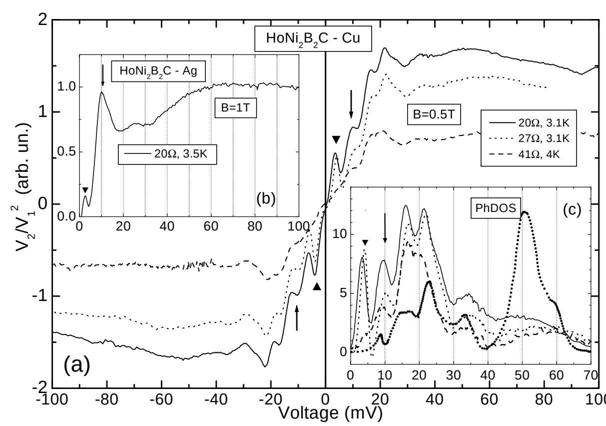

Fig. 1. PC spectra ($V_2/V_1^2 \propto -d^2I/dV^2(V) \propto \alpha^2_{PC}(\epsilon)\,F(\epsilon)$) of several $HoNi_2B_2C$–Me (Me=Cu, Ag) PCs. Magnetic field is applied to suppress superconductivity. Insets: (b) spectrum with main 10-mV CEF peak. ↓ marks CEF peak, ▼ marks "magnetic" peak about 4 mV, (c) spectra from the main panel with subtracted background along with $LuNi_2B_2C$ PhDOS [2].

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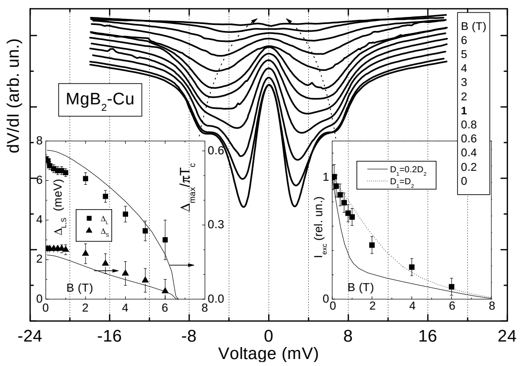

Fig. 2. dV/dI of a MgB_2–Cu contact at 4.5K in a magnetic field. Dashed arrows follow qualitatively the large gap evolution. Large and small gap (left inset) and excess current (proportional to the integral intensity of dV/dI minima, right inset) vs magnetic field for the contact from the main panel along with theoretical prediction (solid curves) calculated in [6].

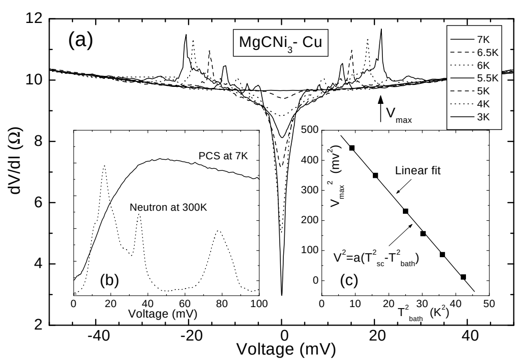

Fig. 3. dV/dI of a $MgCNi_3$-Cu heterocontact below $T_c \simeq 7$ K. Insets: (b) second derivative of $I(V)$ curve for the same contact just above T_c in comparison with smoothed phonon DOS [4], (c) peak position in dV/dI vs temperature.

the Neél (∼6K) temperature. More often the spectra demonstrate completely smeared phonon maxima, but expressed CEF peak (see Fig. 1b). This points to the importance of CEF excitations in the transport as well as in the SC properties of $HoNi_2B_2C$.

MgB_2 has multi-band electronic structure with SC gaps distributed over the Fermi surface being $\Delta_\sigma \approx 7$ meV for the σ-band and $\Delta_\pi \approx 2$ meV for the π-band [5]. This is seen in the dV/dI curves exhibiting two sets of minima (Fig. 2). We have measured magnetic field dependence of both gaps along with an excess current. The latter has positive curvature, unlike for common superconductors, which is connected [6] with the specific multi-band electronic structure of MgB_2.

$MgCNi_3$ becomes superconducting below about 8 K despite the high content of magnetic Ni, which may favor an unconventional pairing mechanism. The large residual resistivity ρ_0 of $MgCNi_3$, like that in amorphous metal, requires at first an ascertainment of the

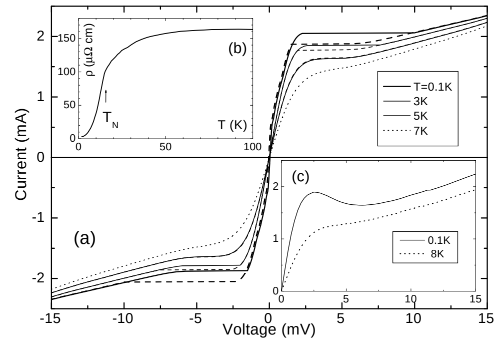

Fig. 4. $I(V)$ characteristics of a UPd_2Al_3 break junction with $R_n = 0.66\,\Omega$ at the indicated temperatures. Solid (dashed) lines correspond to sweeps with increasing (decreasing) current. The hysteretic loops become smaller when the temperature rises and vanish above ~ 5 K. Inset: (b) $\rho(T)$ for the bulk compound, (c) $I(V)$ characteristics of the UPd_2Al_3 PC at two temperatures, calculated for the thermal regime [7]

current flow regime in PC. As it is discussed in [8] some distinct features as spikes and zero-bias minimum in dV/dI of $MgCNi_3$ PCs in SC state (Fig. 3) have relation neither to order parameter (or gap) nor to unconventional ground state. The regime of current flow in $MgCNi_3$ PCs is likely thermal and PC spectrum shows no discernible phonon features (Fig. 3b).

UPd_2Al_3 has much lower ρ_0 compared to $MgCNi_3$, however $\rho(T)$ increases steeply by approaching the AF transition at 14 K (Fig. 4b). We have observed that submicron PCs of UPd_2Al_3 have *hysteretic* $I(V)$ characteristics when the junction is driven by a current source (Fig. 4). It turned out that $I(V)$ can be reproduced theoretically by assuming the constriction to be in the thermal regime [7]. Thus, these PCs represent nonlinear devices with N-shaped $I(V)$ curves (Fig. 4c) that have a negative differential resistance. Such behavior can be expected for PCs with other magnetic materials, which resistivity increases steeply when magnetic order is destroyed by thermal fluctuations.

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